Appendix C

OVERLAND FLOW DESIGN EXAMPLE

C.1 Introduction

The purpose of this design example is to demonstrate the design procedures described in Section 6.4. This example represents a preliminary design suitable for Step 1 facility planning. It does not go into the details of system components such as specific equipment and hardware.

C.2 Statement of the Problem

Community C, a small rural community in the mid-Atlantic United States, has a 30 year old wastewater treatment system that is not meeting its discharge permit. The community is totally residential with no industry discharging into the sewer system and has 20 year design wastewater flow projection of 1,890 m^3/d (0.5 Mgal/d). The objective of this project is to provide the community with a wastewater treatment system capable of meeting the discharge requirements.

C.3 Design Considerations

C.3.1 Wastewater Characteristics and Discharge Requirements

The raw wastewater characteristics are presented in Table C-1. Although not listed in Table C-1, the concentrations of trace elements are within the typical range for municipal wastewater, and are therefore amenable to land treatment. The state regulatory agency has imposed the following limitations for any point source discharge; BOD_5, 20 mg/L; suspended solids, 20 mg/L; fecal coliforms, 200 MPN/100 mL.

TABLE C-1
RAW WASTEWATER CHARACTERISTICS

Parameter	Value
BOD_5, mg/L	200
Suspended solids, mg/L	200
Total nitrogen, as N, mg/L	40
Ammonia as N	25
Organic as N	15
Total phosphorus, as P, mg/L	10

C.3.2 Climate

Average monthly temperature and precipitation data for Community C were obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Asheville, North Carolina, and are shown in Table C-2. A 25 year, 1 hour storm for the community was determined using the Rainfall Frequency Atlas of the United States, U.S. Department of Commerce, Technical Paper 40, and was found to yield 8.1 cm (3.2 in.).

TABLE C-2
AVERAGE METEOROLOGICAL CONDITIONS

Month	Temperature, °C	Precipitation (Pr), cm	Potential evapo-transpiration, (ET), cm	Net precipitation (Pr-ET), cm
Jan	5.2	8.7	0.3	8.4
Feb	6.2	9.3	0.2	9.1
Mar	10.0	10.2	1.9	8.3
Apr	14.7	8.8	4.3	4.5
May	19.6	9.2	9.3	-0.1
Jun	24.3	9.1	13.1	-4.0
Jul	25.8	11.2	15.6	-4.4
Aug	25.1	11.3	13.8	-2.5
Sep	22.1	8.2	9.7	-1.5
Oct	16.2	8.5	5.2	3.3
Nov	10.2	7.0	2.0	5.0
Dec	5.8	9.3	0.2	9.1
Year	14.2	110.8	75.6	35.2

C.4 Site Evaluation and Process Selection

C.4.1 General Site Characteristics

A preliminary site investigation determined that approximately 35 ha (86 acres) of land near the existing wastewater treatment system is available (Figure C-1). A USGS map showed the site to have a moderate to gentle slope that drains naturally into Crooked Creek, the small stream that receives the treated effluent from the existing treatment system. A large portion of the site is wooded with pines, hardwoods, and thick undergrowth.

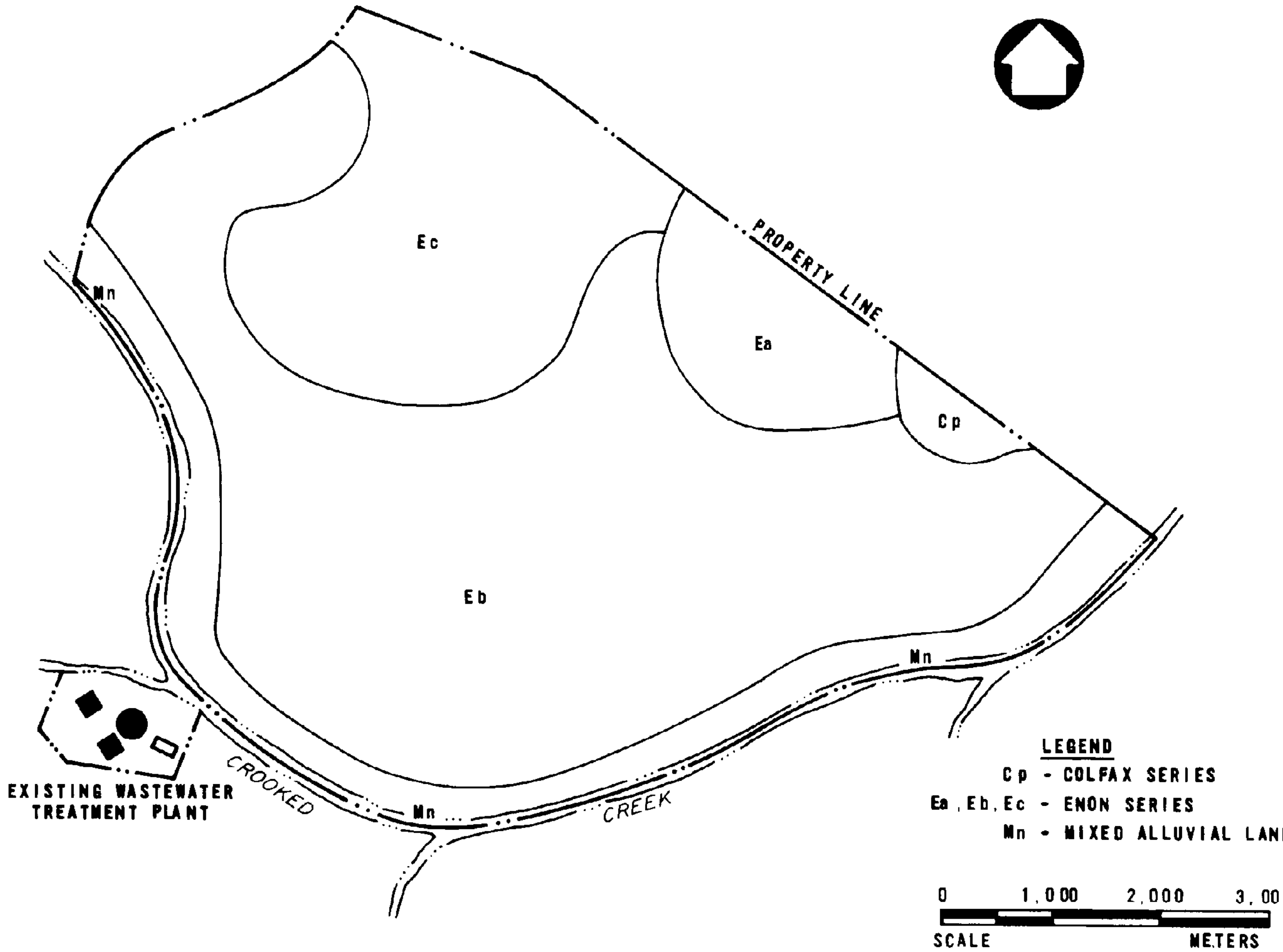


FIGURE C-1
PROPOSED OVERLAND FLOW TREATMENT SITE

C.4.2 Soil Characteristics

As shown in Figure C-l, the proposed site is dominated by soil of the Enon series. These soils have a fine sandy loam top soil underlain with clays having a slow permeability. Also present is Colfax sandy loam, which is underlain with clay loam and mixed alluvial land along the stream. Both of these soils have permeabilities ranging from slow to very slow.

C.4.3 Process Selection

The slow permeability of the Enon soils will prohibit the use of RI and will severely limit the use of this site for SR treatment. Preliminary estimates indicated that OF treatment was more cost effective than an SR system on this site and was lower in total present worth than the best conventional secondary treament and discharge alternative. Therefore, OF treatment was the alternative selected by Community C.

C.5 Distribution Method

High pressure sprinklers are used in this example to illustrate the procedure. Gravity distribution is usually more cost effective and energy efficient. For high solids content wastewaters, such as food processing effluent, sprinklers can offer the advantage of greater solids dispersion over the application area.

C.6 Preapplication Treatment

Continued operation of the existing treatment facilities would not be cost effective because of the need for sludge treatment and disposal. A new system consisting of the minimum recommended treatment, that is, two-stage screening, was selected. An economic analysis indicated the cost savings from using less land (higher hydraulic loading rates) did not offset the cost of preapplication treatment (Section 6.3) beyond screening.

The two-stage screening system includes a coarse screen (bar rack) and a fine screen. Since sprinkler application was selected as the distribution method, the fine screen must be capable of removing particles that could clog the sprinkler nozzles. The screen mesh will be 1.5 mm (0.06 in.), as recommended in Section 6.3. The new two-stage screening system will be located at the headworks of the abandoned existing plant.

C.7 Wastewater Storage

C.7.1 Storage Requirement

The required storage for this project was calculated using historical air temperature data obtained from the NOAA in Asheville, North Carolina, and the design method described in Section 6.4 for moderate climate zones. Twenty years of data were reviewed for the air temperature limitations specified by the design method to determine the critical year, or the year that would have required the most storage. The required storage days for the critical year are given on a monthly basis in Table C-3. The total storage requirement is 44 days, or 83,160 m^3 (22.0 Mgal) of wastewater at the design flow of 1,890 m^3/d (0.5 Mgal/d).

TABLE C-3
STORAGE REQUIREMENTS

Month	Storage, days	Potential application, days
Nov	0	30
Dec	15.5	15.5
Jan	14.5	16.5
Feb	14.0	14.0
Mar	0	31
Total	44.0	

The storage pond will be filled only during cold weather when temperatures fall below -4 °C (25 °F). The procedure for applying the stored wastewater on the OF site is described in Section 6.5.

C.7.2 Storage Facility Description

Storage consists of a facultative pond. The design depth is 2 m (6.6 ft) and the surface area is 4.2 ha (10.4 acres). Wastewater will be diverted to storage in December, January, and February and will be drawn out of storage over the period from March through May. The daily BOD loading on the storage pond during the days of storage will be 89 kg/ha (80 lb/acre) and odors should not be a problem. The net precipitation falling on the storage pond will add 18,600 m^3 (5 Mgal) so that a total of 101,760 m^3 (26.9 Mgal) will have to be removed from the storage pond each spring. Seepage from the pond is neglected for the storage period.

The pond berm has interior and exterior side slopes of 3:1 (horizontal:vertical), a height above grade of 2.6 m (8.5 ft), and a crest width of 3.7 m (12 ft) which will serve as a service road. The interior berm has a 30 cm (12 in.) layer of riprap for embankment protection. The pond is lined with compacted local clay to meet applicable state requirements. The exterior berm slopes are planted to grass. The total area required for the storage pond is 5.4 ha (13.3 acres).

C.8 Selection of Design Parameters

C.8.1 Hydraulic Loading Rate

From Table 6-5, the range of hydraulic loading rates for screened wastewater application is 0.9 to 3 cm/d (0.35 to 1.2 in./d). The selected hydraulic loading rate is 1.4 cm/d (0.57 in./d). This rate has been used successfully with screened raw wastewater in a similar climate (Sections 6.4 and 6.2). A more conservative loading rate is unnecessary because prolonged subfreezing temperatures are not common. A higher loading rate during periods of near freezing temperatures would be inappropriate.

C.8.2 Application Period and Frequency

The application period selected is 8 h/d. This period can be increased to 12 h/d during drawdown from storage and during harvest periods (Table 6-5). The application frequency is 7 d/wk.

C.8.3 Slope Length and Grade

As recommended in Section 6.4.6, the minimum slope length for OF using full circle sprinklers is 30 m (100 ft) plus one sprinkler radius. The sprinklers chosen for this project (Section C.9) have a spray radius of 21.4 m (70 ft). Thus, the minimum slope length is 51.4 m (168 ft). To be more conservative, the design slope length is 61 m (200 ft). The grade will range from 2 to 4% depending on existing grades that are within this range.

C.8.4 Application Rate

Using the selected hydraulic loading rate, application period and frequency, and slope length, the application rate is calculated:

$$R_a = \frac{L_w S}{P(100\ \text{cm/m})}$$

where R_a = application rate, $m^3/m \cdot h$

L_w = hydraulic loading rate, 1.4 cm/d

S = slope length, 61 m

P = application period, 8 h

$$R_a = \frac{1.4(61)}{8(100)}$$
$$= 0.071\ m^3/m \cdot h$$

This is within the acceptable range from Table 6-5.

C.8.5 Land Requirements

The slope area can be calculated from Equation 6-2.

$$A_s = [Q(365) + \Delta V_s]/(D_a L_w(100)]$$

where A_s = slope area, ha

Q = average daily flow, m^3/d

ΔV_s = net change in storage = 18,600 m^3/yr (C.7.2)

D_a = number of operating days per year

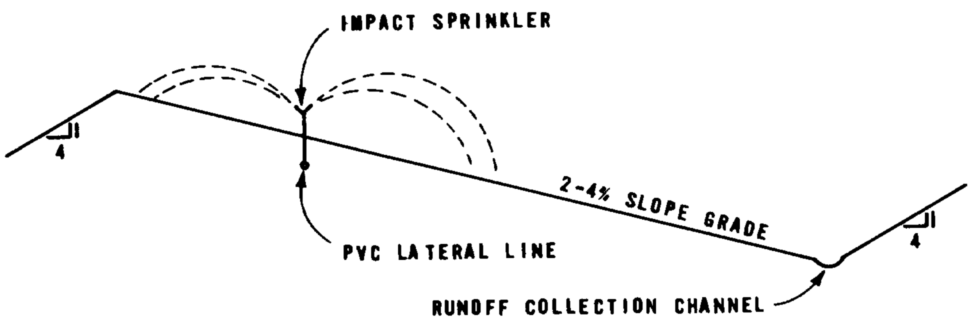
L_w = hydraulic loading rate, cm/d

$$A_s = [1{,}890(365) + 18{,}600]/[(365 - 44)(l.4)(100)$$

$$= 15.8\ \text{ha (39 acres)}$$

C.9 Distribution System

Impact sprinklers with 7.1 mm (9/32 in.) diameter nozzles operating at 41.4 N/cm^2 (60 $lb/in.^2$) are selected to apply the wastewater. The OF slope and the sprinkler positions are shown in Figure C-2. the sprinkler spacing of 24 m (80 ft) provides adequate overlap of the spray diameter which is 42.7 m (140 ft).



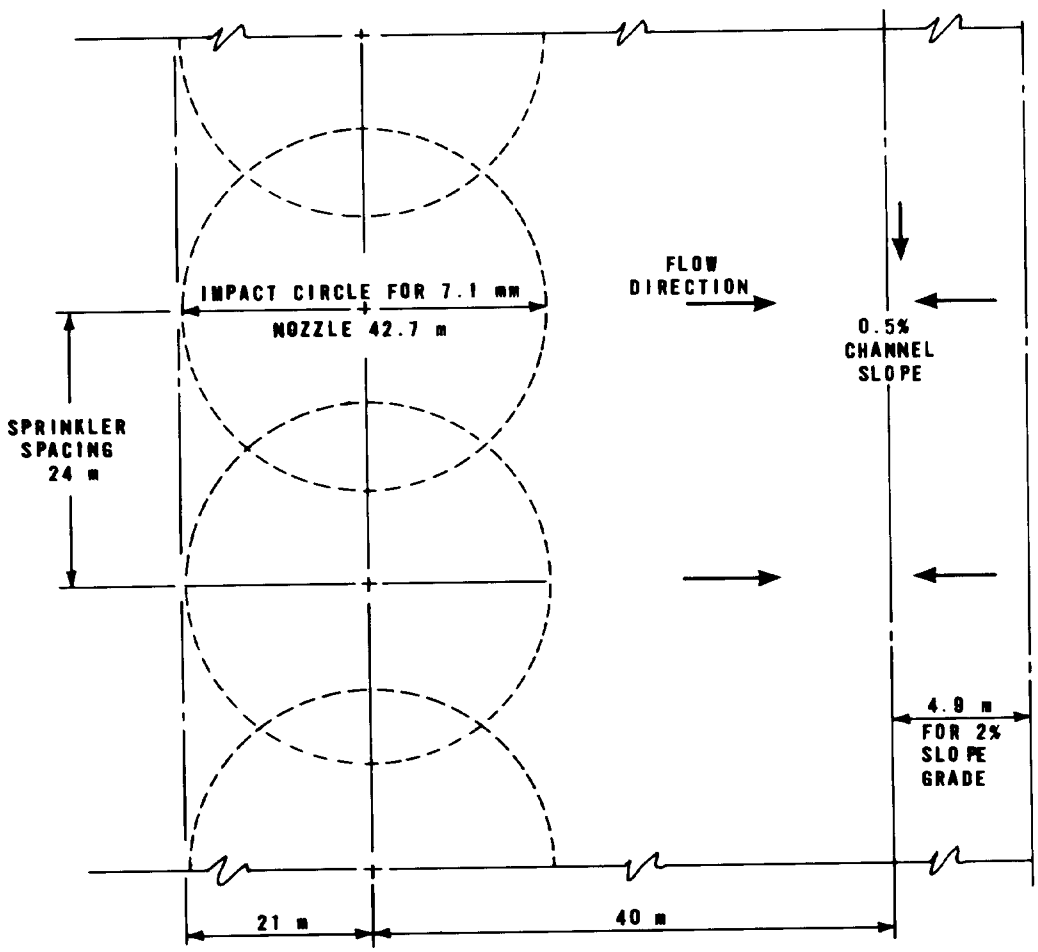


FIGURE C-2
TYPICAL OVERLAND FLOW SLOPE

C.10 Preliminary System Layout

The field area and slope lengths have now been determined. Given these, a preliminary layout of the treatment system was made on a USGS map using the guidelines from Section 6.6. The dimensions for storage have also been determined and were added to the overall layout. Using this and remembering that area is required for collection waterways, service roads, buffer zones, etc., the size of the survey area was determined. It can not be overemphasized that a sufficient amount of land greater than the apparent needs must be surveyed so that changes in the system layout that may occur do not require that additional land be surveyed. This not only adds a greater cost to the project, but also takes additional time that delays the design.

For this project, the entire site was surveyed so that any future expansions to the system could be performed without another survey. From this survey, a contour map with contour intervals of 0.3 m (1.0 ft) was developed (Figure C-3); however, due to the scale of Figure C-3, only the 3.05 m (10.0 ft) contours are used.

C.11 System Design

C.11.1 Treatment Slopes

Given the slope area requirements and the slope length, the contour map developed from the survey, and the site development guidelines in Section 6.6, the treatment slopes were laid out (see Figure C-4). This layout has the slopes all graded in the same direction (southeast) while the runoff collection channels convey the effluent northeast to a collection waterway. With this layout, all effluent is discharged from the site at a single point as indicated on the figure.

C.11.2 Runoff Channel Design

The runoff collection channels are formed by the intersection of the foot of one treatment slope with the backslope of the next treatment slope (Figure C-2). These channels will be graded to no greater than 25% of the slope grade of the treatment slope to prevent cross-flow on the treatment slope. This slight grade will be sufficient to cause flow to the collection waterways and will preclude the need for any type of erosion protection other than planting the channels with the same grasses as are used on the treatment slopes.

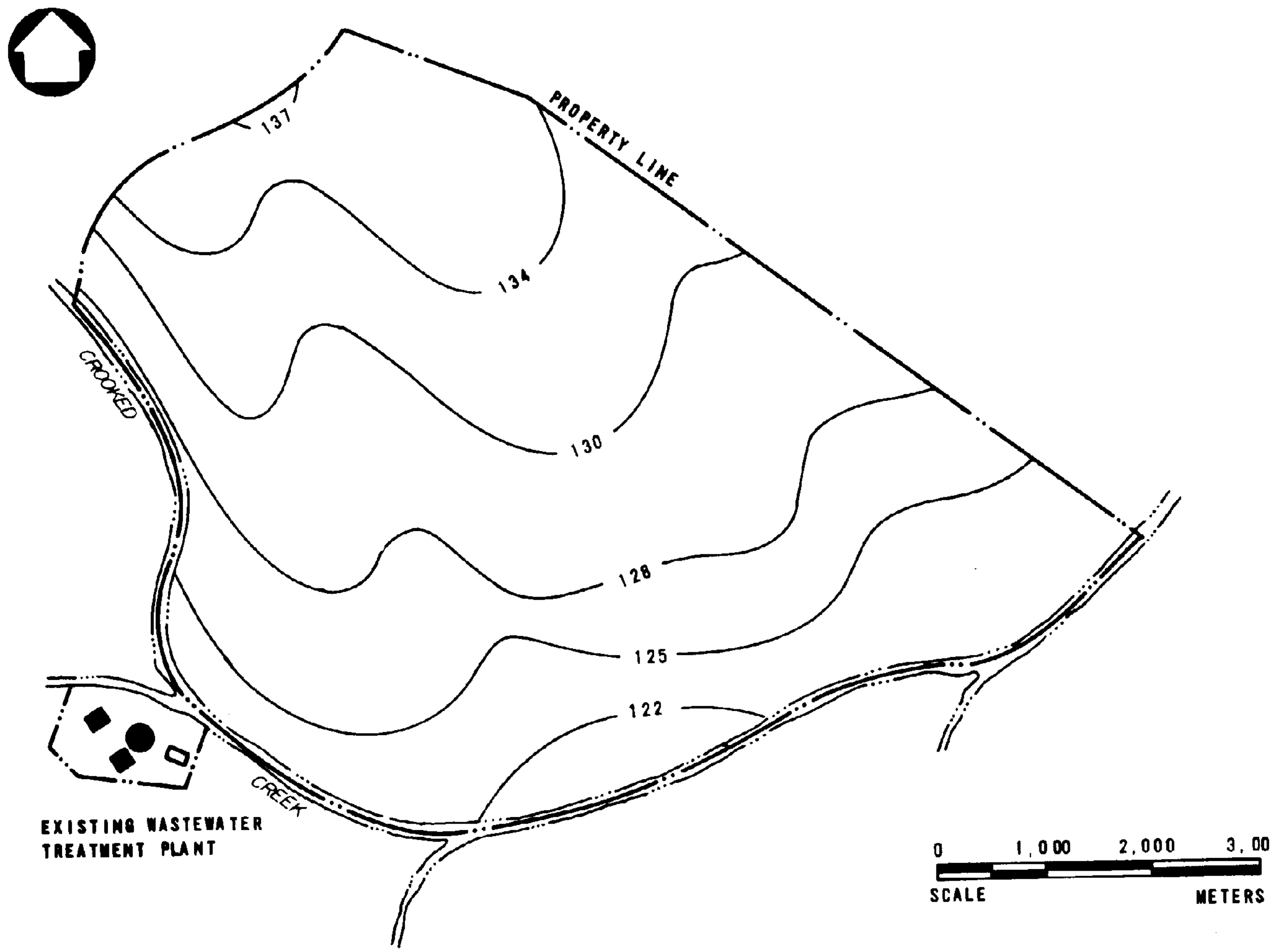


FIGURE C-3
CONTOUR MAP OF PROPOSED OVERLAND FLOW TREATMENT SYSTEM

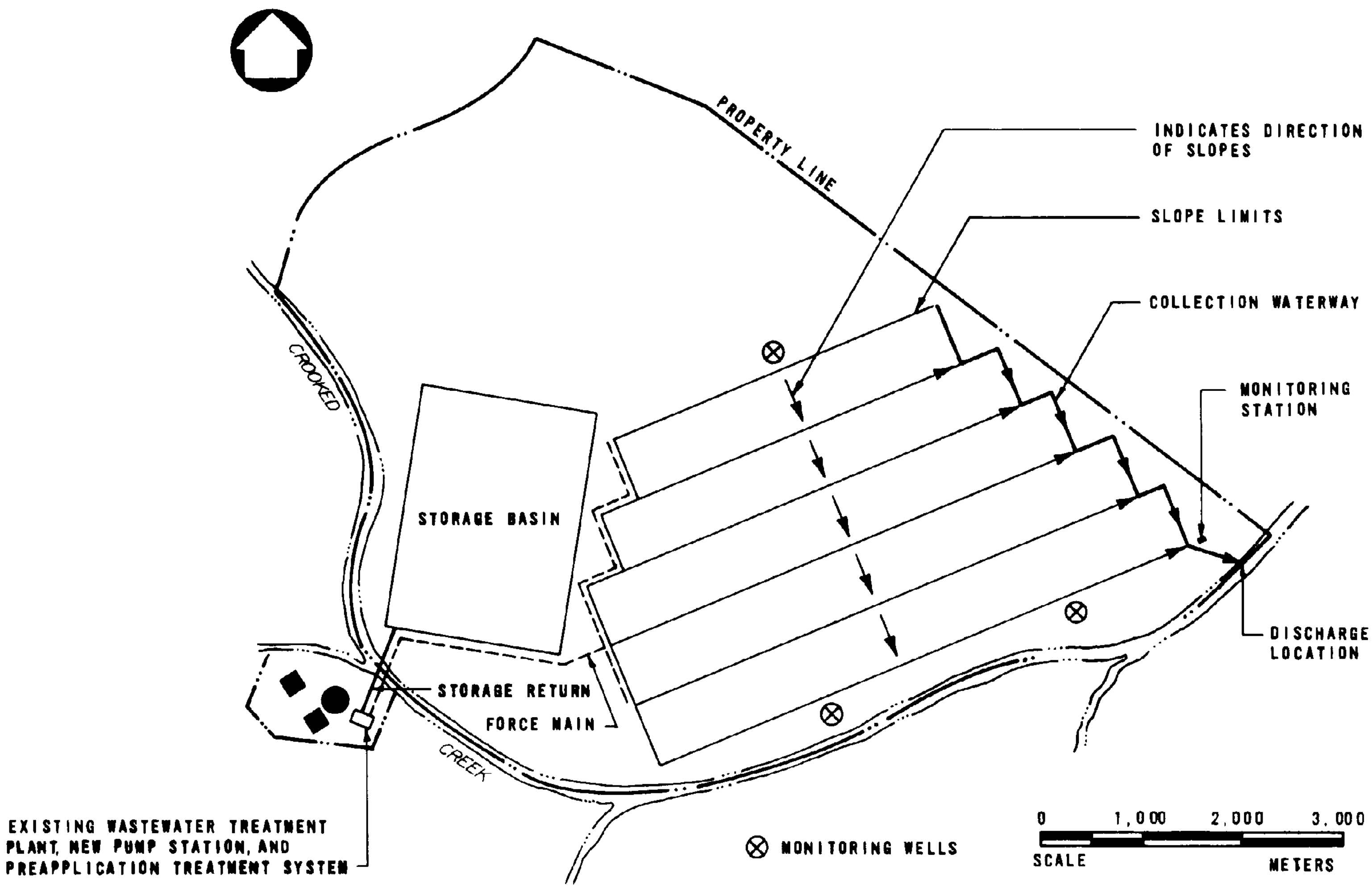


FIGURE C-4
OVERLAND FLOW SYSTEM LAYOUT

C.11.3 Collection Waterways

The collection waterways transport the effluent from the runoff collection channels to the receiving stream (Figure C-4). These waterways were designed to handle both the design runoff from the system plus precipitation that falls on the site during a 25 year storm.

The Rational Method, which can be found in any soil and water engineering text, was used to determine the storm runoff from the treatment slopes. The 25 year storm runoff for each slope was determined and the flows accumulated as each runoff collection channel contributed flow to the collection waterway. The flow increases in quantity as it comes downgrade until all runoff collection channels have fed it. Therefore, the collection waterway must also increase in size as it comes downgrade to prevent high flow velocities that cause erosion.

Working from the treatment slope with the highest elevation down (northeast corner of spray field to southeast corner), the waterway was designed for the expected effluent runoff and the 25 year stormwater flow for each section between runoff collection channels. The procedure for designing grassed waterways, which can be obtained from the SCS, was used to size each section. Since the topography of the site is such that the collection waterway will have a slope of 4% or less, there was no need for embankment protection at bends; the grass is sufficient to prevent erosion.

C.11.4 Pumping System

The pumping system includes three pumps, each with a capacity of 1,325 L/min (350 gal/mm) at a total head of 72.5 m (238 ft). The headloss was determined by summing all the headlosses, from the farthermost sprinkler back to the pump, of the critical piping path or that path that produces the greatest headloss.

The pumps work in parallel and feed a 20.3 cm (8 in.) force main that runs to the spray field. The combined capacity of the three pumps is three times the average design flowrate so there is an adequate safety factor for peak flows and diurnal fluctuations.

The pumping station is located immediately after the two stage screening unit on the existing treatment plant site. As shown in Figure C-4, the storage basin is at a higher elevation, which means wastewater must be pumped to storage and then flow back to the pumping station through a separate pipeline by gravity. Sufficient land was not available to locate the storage basin between the screening unit and the pumping station to allow gravity flow into storage and out to the pumping station. During favorable days in the spring, a valve is opened on the return pipeline from the storage pond to the pumping station and wastewater is applied to the slopes at 1.5 times the average daily flowrate.

C.11.5 Monitoring and Collection Systems

A monitoring station is located on the site, as shown in Figure C-4. This station consists of a Parshall flume with a continuous flow metering device and a composite sampler. The Parshall flume was designed to handle the 25 year storm flow without sustaining significant damage. A standby chlorination system was installed at this location and three ground water monitoring wells were installed as shown in Figure C-4 to satisfy state regulatory requirements.

C.12 Land Requirements

The final land area requirement was determined after all the components of the OF system had been sized and located on the site plan. A 15 m (50 ft) buffer zone around the application site was recommended by the state agency since residential developments are close to the site. The buffer zone will remain wooded and will require 2.3 ha (5.7 acres) of land. All of the land requirements of the system are listed in Table C-4. Although the total land requirement is 29.3 ha (72.3 acres), the entire 35 ha (85 acre) site was purchased since the owner refused to sell only a portion of the property.

TABLE C-4
LAND REQUIREMENTS

Item	Area	
	ha	acres
Field area with collection channels	15.8	39.0
Storage pond	5.4	13.3
Buffer zone	2.3	5.7
Miscellaneous		
Roads, collection waterways, monitoring station	1.1	2.7
Surplus land[a]	4.7	11.6
Total	29.3	72.3

a. Surplus land is that land which does not fit economically into the grading plan.

C.13 Cover Crop Selection

Based on experiences with varieties of grasses at other OF systems, it was decided to use the mixture given in Section 6.7 which includes Reed canarygrass, tall fescue, redtop, dallisgrass, and ryegrass. The local agricultural agent concurred and also suggested orchardgrass be added to the mix since this grass flourished in the area.

C.14 System Costs

Total costs for the OF system for Community C are presented in Table C-5. Capital costs were estimated using the EPA technical report on Cost of Land Treatment Systems [1]. Costs were updated to September 1980 using the EPA Sewage Treatment Plant Construction Cost Index value of 362 and the EPA Sewer Construction Cost Index of 387. Contractor*s overhead and profit are included in the cost estimates. The land was assumed to cost $4,900/ha ($2,000/acre). Operation and maintenance costs were estimated using the cost curves and current local prices for power and labor. Present worth was determined using an interest rate of 7-1/8% for 20 years.

TABLE C-5
COST OF COMMUNITY C OF SYSTEM
Thousands of Dollars, September 1980

Capital costs	
Preapplication treatment	42
Pumping	271
Force main	29
Piping to and from storage	20
Storage pond	316
Site clearing	70
Slope construction	60
Runoff collection	14
Distribution (sprinklers, laterals, controls)	72
Agriculture (preparation and seeding)	20
Service roads	24
Chlorination and flow monitoring	56
Monitoring wells	5
Contingencies (30%)	300
Land	172
Total capital costs	1,471
Operation and maintenance costs	
Annual labor	27
Annual materials	7
Annual power	8
Total operation and maintenance costs	42
Total project costs	
Total capital costs	1,471
Present worth of operation and maintenance	441
Total present worth of costs	1,912
Present worth of salvage value of land	(78)
Net present worth	1,834

C.15 Energy Budget

Pumping, crop production, and chlorination require quantifiable primary energy. For pumping raw wastewater, stored wastewater, and accumulated precipitation at a head of 72.5 m (238 ft), 222,000 kWh/yr is required. Crop harvest will require 20,000 kWh/yr and disinfection, if used, will required 5,000 kWh/yr. The total primary energy budget is 247,000 kWh/yr. If a gravity distribution system had been possible, the pumping requirements would have been reduced to about 58,000 kWh/yr due to the lower pumping head requirement of approximately 20 m (66 ft).

C.16 Alternative Design Methods — Design Example

The data used to design the OF system in the previous example will be used with the alternative CRREL and UCD design methods. These two methods determine the land area and loading requirements for a system and thus would not alter the other parts of the design procedure just used. These methods represent a rational OF design procedure, but have been used to a limited extent for design as of September 1981.

C.16.1 CRREL Method

Given:

Daily flowrate = 1,890 m^3/d
Influent BOD = 200 mg/L
Effluent BOD = 20 mg/L
Storage requirement =44 days
Volume of precipitation in storage = 18,600 m^3/yr
Runoff fraction, r = 60%

Constants for the design equation are (see Section 6.11.1):

$A = 0.52$
$K = 0.03\ min^{-1}$

The necessary calculations are:

1. Calculate detention time on the slope:

$$\%\ \text{BOD removal} = \frac{(1.0)(200) - 0.6(20)}{(1.0)(200)} \times 100 = 94\%$$

Using Equation 6-8 (Section 6.11.1.2)

$$E = (l - A_e^{-Kt})100$$

$$94 = (1 - 0.52e^{-0.03t})100$$

$$t = 72 \text{ min}$$

2. Calculate average overland flowrate. The site investigation revealed the site had a gentle slope of 4 to 6%. For design purposes, the natural slope of 5% will be used and a section size of 40 m long and 30 m wide (131 by 98 ft) will be used, based on site characteristics. The average overland flowrate is calculated using Equation 6-9 from Section 6.11.1.2.

$$q = (0.078S)/(G^{1/3}t)$$

$$= [0.078(40 \text{ m})]/[(0.05)^{1/3}(72)]$$

$$= 0.12 \text{ m}^3/\text{m}\cdot\text{h}$$

3. Calculate application rate. Using Equation 6-10 from Section 6.11.1.2, the application is calculated.

$$Q = qw/r$$

$$= [(0.12 \text{ m}^3/\text{m}\cdot\text{h})(30 \text{ m})]/[(l + 0.6)/2]$$

$$= 4.5 \text{ m}^3/\text{h per section}$$

4. Calculate annual loading rate. An application period of 8 h/d and an application frequency of 7 d/wk will be used in this example. Since the storage requirement is 44 days and the application frequency is 7 d/wk, the number of days of application is 321 d/yr. The annual loading rate per section is therefore:

Annual loading = (321 d/yr)(8 h/d)

x (4.5 m^3/h per section)

Rate per section = 11,556 m^3/yr

5. Calculate total annual water volume. Given a daily flowrate of 1,890 m and a volume of precipitation that ends up in the storage as 18,600 m^3/yr, the total annual water volume is 708,450 m^3 /yr.

6. Calculate land area requirements. The number of sections required is:

No. sections = (708,450 m^3/yr)

÷ (11,556 m^3/yr per section)

= 62 sections

The total area requirement is

Area = [(62 sections)(30 m x 40 m/section)

÷ 10,000 m^2/ha

= 7.4 ha (18.3 acres)

For comparison to the previous example, the weekly hydraulic loading rate can be calculated as:

4.5 m^3/h x 8 h/d x 7 d/wk = 252 m^3/wk

252 m^3/wk x (l/1,200)(section/m^2
x 100 cm/m
= 21 cm/wk

C.16.2 University of California, Davis, Method

Given:

Daily flowrate = 1,890 m^3/d
Influent BOD = 200 mg/L
Effluent BOD = 20 mg/L
Storage requirement = 44 days
Volume of precipitation in storage = 18,600 m^3/yr

Constants for the design equation are (see Section 6.11.2):

A = 0.72
n = 0.5
K = 0.01975 m/h

The necessary design calculations are:

1. Compute the required removal ratio C_s/C_o.

C_s/C_o = 20/200 = 0.10

2. The length of slope is not restricted by topography, so select a value for the application rate (q) in the valid range of the model (see Section 6.11.2)

Select $q = 0.16\ m^3/m\cdot h$

3. Compute the required value of slope length (S) using Equation 6-11 from Section 6.11.2.

$$C_s/C_o = Ae^{[(-KS)/(q^n)]}$$

$$.1 = 0.72e^{-0.04938S}$$

$$S = 40\ m$$

4. Select an application period (P)

P = 8 h/d

5. Compute the average daily flow to the OF system using 44 days of storage, a 7 d/wk application frequency, and 18,600 m^3/yr additional water in storage from precipitation.

$$Q = [(365\ d)\ (1{,}890\ m^3/d)$$

$$+ 18{,}600\ m^3)]/(365 - 44)$$

$$= 2{,}207\ m^3/d$$

6. Compute the required wetted area using Equation 6-5 from Section 6.11.2.

Area = QS/qP

$$= [(2{,}207\ m^3/d)(40)]/[(0.16\ m^3/m\cdot h)$$

$$\times\ (8\ h)(10{,}000\ m^2/ha)]$$

$$= 6.9\ ha\ (17.0\ acres)$$

For comparison to the other examples, the weekly hydraulic loading rate can be calculated as:

$$(2{,}207\ m^3/d)(7\ d/wk) = 15{,}449\ m^3/wk$$

$$(15{,}449\ m^3/wk)(l/68{,}500\ m^2)(100\ cm/m) = 22.6\ cm/wk$$

C.16.3 Comparison of Methods

Although the CRREL and UCD equations appear different, the basic approach and calculation method are quite similar. Combining and rearranging Equations 6-8 and 6-9 from the CRREL method produce:

$$M_s/M_o = 0.52e^{(-0.00234S)/(G^{1/3}q)} \tag{6-13}$$

where M_s = mass of BOD at point S, kg
M_o = mass of BOD at top of slope, kg
S = slope length, m
q = average overland flowrate, $m^3/m \cdot h$
G = slope grade, m/m

This is quite similar to the UCD Equation 6-11:

$$C_s/C_o = 0.72e^{(-0.01975S)/(q^{0.5})}$$

All terms as defined previously.

The major difference in these two rational approaches are the use of slope as a variable in the CRREL equation and the value of the coefficients and exponents. Comparison of the results from all three methods are tabulated below:

Method	Land area, ha	Slope length, m	Hydraulic loading, cm/wk
Traditional	15.8	60	10
CRREL	7.4	40	21
UCD	6.9	40	22.6

The major difference between the three methods is the slope length required. The hydraulic loadings are similar since the traditional method would permit at least 15 cm/wk during the warm months. The CRREL and UCD methods are based on assumed gravity distribution, so a shorter slope can be used since there is no need to provide space above the application point for full circle sprinkler impact. If gravity application had been used in the traditional design, the gated pipe could have been placed at the sprinkler nozzle location shown in Figure C-2. This would result in a 40 m (130 ft) slope length which is identical to that determined by the rational methods.

C.17 References

1. Reed, S.C. et al. Cost of Land Treatment Systems. U.S. Environmental Protection Agency. EPA-430/9-75-003. September 1979.